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The ERP Detection of Mental Arithmetic Strategies

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Abstract. Strategy use is a mental operation which aims directly at its target. In order to investigate brain activity during mental arithmetic strategies using, subtraction answers-discrimination tasks were used through 8 healthy subjects with the Event-related Potentials (ERPs) technique. The results showed: (1) The principal components of ERP were: N1, P1, P2, P300 and N400. (2) At the F3, C3 point, stage 4 induced more negative wave than stage 1; At F4, C4, P3 and P4 point, stage 4 induced more positive wave than stage1. (3) Activation of brain areas mainly included Temporal lobe, Prefrontal cortex and Parietooccipital. (4) With the subjects gradually skilled in using strategies, activated brain region gradually moved from back to front; meanwhile the right side had higher active level than the left of brain. Further exploration need to describe more detailed brain potentials during mental arithmetic strategies using in other conditions.

Introduction

Usually, those who are best able to execute a current strategy are those who are the most likely to identify new, more effective methods. So strategy use is a manifestation of a higher level of intellectual activity. Several findings in the literature indicate that one of the main source of children's cognitive ability is to use strategies to solve problems. Recent decades, the characteristics and mechanisms of strategy use of children and adolescents were concerned in cognitive psychology, developmental psychology and educational psychology. Mental arithmetic is an arithmetic operation in the absence of external tools (such as a pen, a piece of paper, or a calculator, etc.), which is also regarded as the overall performance of one's computing ability, memory and learning ability. To explore mental arithmetic strategy use from the neurophysiological angle has become a hot area in mental arithmetic research in recent years(Chang Liu,2010). There were some studies used EEG technology (eg., Harmony et al., 1999; Harmony et al, 2010), for example, Dimitriadis et al. (2010) investigated the brain electrical characteristics of mental arithmetic of 18 subjects by multichannel EEG, found that the deactivation of default mode network and could be attributed to inhibitory mechanisms activated during mental tasks.

However, we are still rather vague in the specific characteristics of brain electrical activity (brain mechanisms) of mental arithmetic. Event-related potentials (ERPs) is a new EEG technology which is more reliable and accurate. At present, ERPs are widely used in brain research, and it has also made great achievements in psychology, physiology, cognitive neuroscience and clinical medicine. ERPs are known as "the window to observe brain function" with high value both in research and application fields. In this research, we tried to use ERP technology to investigate the brain electrical activity of mental arithmetic under guiding condition. The importance of this research were as following: Theoretically, to explore the brain electrical activity when using explicit strategies so as to provide physiological evidence of individual strategy skill's development. In practical, to provide an empirical basis for improving strategies teaching, and further test the teaching model which was designed to promote children's mathematics cognitive strategies mastering.

Methods

Subjects. Random sample 10 freshmen, average age was 20. Test content and its methods were exactly the same. The data of 8 subjects were valid.

Experimental Material. We developed the subtraction mental arithmetic tasks and designed 3-digit minus 2-digit subtraction calculations in order to avoid the possibility of automatic operation. (Fig. 1) The formula would appear on the top of the screen while the two alternative answers appear below. These stimuli implied parity strategy (parity strategy refers to, odd – even = odd or even – odd = odd, even – even = even).

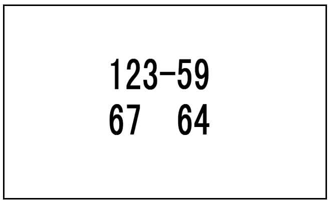

Fig. 1 Stimuli

Experimental Procedure. Before the experiment, subjects were asked to learn the strategies. The whole experiment had 4 blocks, 200 stimuli in total. We chose 17-inch LCD monitor as our presentation device, firstly, we showed fixation ("+") 500ms, and then presented subtraction calculations, subjects should react as soon as they saw the stimuli, stimuli would immediately disappear into the next fixation, and it would show fixation automatically if there was no response in 2000ms. Time interval between each stimulus was 500ms. Just as it showed in Fig. 2.

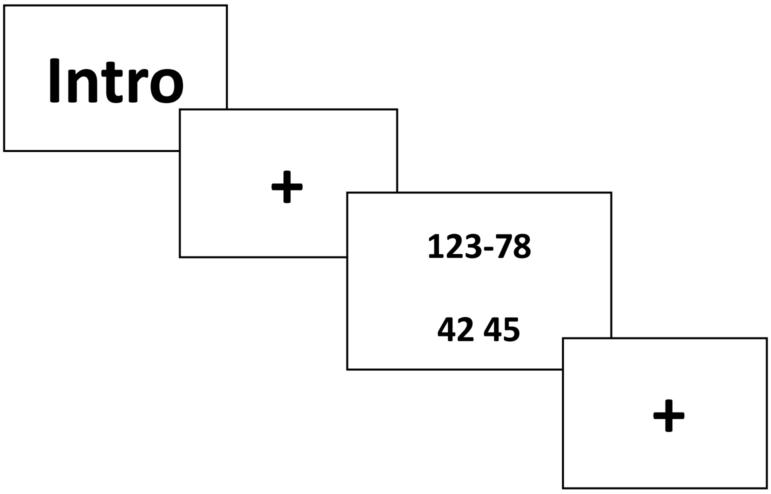

Fig 2 Procedure

There was an introduction in front of each block, said that: "Hello, Dear student! Welcome to participate in our experiment. During the experiment, subtraction formula will appear on the screen quickly. There is a law in these formula, odd – even = odd or even – odd = odd, even – even = even. Please use this law to choose right answer quickly and correctly. Press '1' key if correct answer is on the left, press ‘4’ key if correct answer is on the right. Thank you! If you understand, please press ‘Q’ key to start. ” During the experiment, we prompted subjects to use the strategies with guidance in case of their direct calculation.

Data record. We used EGI 128 EEG recording system to collect EEG data. During detection process, subjects should keep quiet and try to avoid blinking. Intercepting the EEG of 100ms before stimulus and 800ms after stimulus, we put 100ms before stimulus as the baseline EEG to exclude eye movement artifact. Waveform outside the range of ±100μV would be removed as artifact. This study selected 25 electrodes to analyze, except FP1, FP2, O1, O2, O3. EEG data were analyzed by Net Station.

Results and Analysis

Table 1 showed the behavior results: from block 1 to block 4, the Response Time decreases while the accuracy increases. In block 3, the response time was longer than the former and later block, but its accuracy was lower.

Table 1 Response Time and Accuracy

	BLOCK1	BLOCK2	BLOCK3	BLOCK4
Acc	0.878(0.048)	0.905(0.038)	0.815(0.052)	0.930(0.049)
RT	1256.346(92.577）	1167.92(110.669)	1193.863(152.682)	1160.141(127.377)

Note: Figures in brackets denote standard deviation.

Comparison of the average EEG pole. The average overlay charts of whole brain were intercepted in the EEG workstation. According to the purpose of this study and previous research experience, using average amplitude analysis method, we selected the F3, F4, C3, C4, P3, P4 point as the electrodes to analyze. We compared the first stage with the fourth stage, trying to find the EEG changes during the strategies utilization process. Table 2 indicated the amplitudes of 6 electrodes in block 1 and block 4. Each data is the average of 500 time and frequency is 2ms (total time is 1000ms). Their schedules were both -200ms to 800ms. According to the average overlay map, FP1 and FP2 points appeared slow wave drift, which maybe because the two electrodes near the eyes lead to too much resistance. The other electrode points were quite normal, their waveforms were quite stable. In addition, we found that the initial waveforms of the left and right brain areas were significantly different, which indicated the different processing mechanism on both sides of brain.

ERP component analysis. Compared the five electrodes’ waveforms in different time process, the time interval was from -200ms to 800ms. Abscissa was the time process (ms), and vertical axis represented the change of EEG amplitude (μV). F3 point mainly appeared N1, P2, P300, N400 and the late component P700, Compared with stage 1, stage 4 first evoked more negative N1 and more positive P300, the N400 latency delayed about 100ms, and the amplitude of late component was relatively lower. F4 point had clear P300 component. The difference between stage 1 and stage 4 was not significant. The main component in C3 point was P1 and P300. The component induced in C4 point was P300 and N400. Amplitude in P3 point was growing and drifted from the anode to the cathode. In summary, the observed ERP components were N1, P1, P2, P300, N400. However, the wave superposition of P3 point was a bit unstable, it might be caused by the noise or there existed some advanced composition. In the F3, C3 point, stage 4 induced more negative wave than stage 1, while in F4, C4, P3 and P4 point, stage 4 induced more positive wave than stage 1.

Table 2 Amplitude of the different electrodes points in different processes [μV]

	N	Min	Max	Mean	SD
F3(block1)	500	-3.55	3.6	-0.0031	1.80803
F3(block4)	500	-3.53	2.63	-0.3557	1.70144
F4(block1)	500	-1.71	4.51	2.1775	1.8991
F4(block4)	500	-0.68	4.94	2.2289	1.95245
C3(block1)	500	-2.88	0.9	-1.1441	1.06807
C3(block4)	500	-4.26	0.77	-1.6423	1.50561
C4(block1)	500	-0.66	2.08	0.3797	0.67909
C4(block4)	500	-0.53	2.23	0.7036	0.77113
P3(block1)	500	-3.22	0.92	-1.176	1.16459
P3(block4)	500	-2.91	0.68	-1.1077	1.04596
P4(block1)	500	-2.99	0.83	-0.7434	1.16378
P4(block4)	500	-2.18	1.12	-0.2107	0.85377

Topographic analysis. Topographic analysis showed that, throughout the whole calculation process, the relevant regions on both sides of the brain were to participate. Temporal lobe, frontal, parietooccipital were activated one after another. When stimuli was presented, the temporal lobe was first activated, Activated regions were mainly concentrated in frontal cortex and parietooccipital in the later stage, and the right brain had higher active level than the left. In block 1, the activation range was relatively large, and most of the top-occipital was activated; in block 2, activated area reduced toward the back of brain, and concentrated in the junction of posterior parietal and parietooccipital; in block 3, activated area moved to the right frontal lobe and occipital lobe; in block 4, early stimuli did not activate the temporal lobe, and the main activated areas moved to the front of the brain.

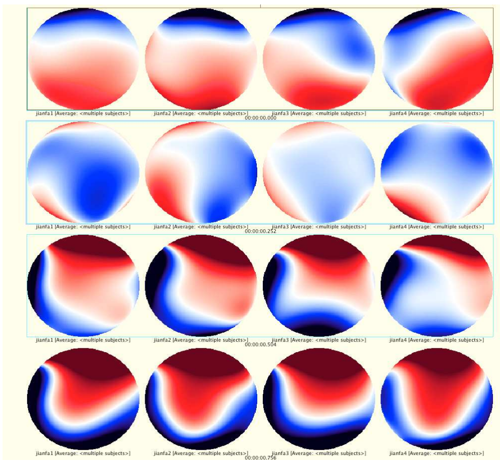

Fig. 3 Topographic maps of using strategies during mental arithmetic

Discussion

The parity strategy was one of the judgment methods，compared to direct computation, it can save psychological resources and improve reaction rate. Therefore, we can study subjects' brain electrical characteristics of the explicit strategy utilization by guiding their use of parity strategy.

Characteristics of ERP. Cognitive potential of learning numbers and calculation is usually assumed as P wave and N wave. Some related research showed that P wave between 200-300ms in incubation period was strongly related to numerical recognition and recall process, and N wave between 450-550ms in incubation period was related to psychological process like consideration and analysis. In this study, the principal components of ERP that we mainly observed were N1, P1, P2, P300, N400. P1 mainly appeared on both sides of occipital area, generally started in the 60-90ms , and its peak was between 100-130ms. In addition,P1 was sensitive to the change of stimulation parameters, direction of spatial attention, and arousal states of subjects. N1 wave appeared after P1, and it was the peak produced on the electrode's head front part in 100-150ms after stimulation, which was generally considered to reflect a process of identification. A clear P2 wave which belongs the early characteristic appeared after the N1 wave and was evoked in 150-250ms. It occured in the central of the head front and scalp area, mainly reflecting the number of physical properties of the brain, such as digital signs, digital form, and even the process of early identification of number sense. P300 occured in parietal region, and appeared in 250-350ms after stimulation, and its characteristic sign was sensitivity of target stimuli. Researches on mathematical cognition in children also showed that calculations included N1, P2, N2, P300, N300 (eg., Su Runping, 2007; Li Mei, etc., 2008).

Variation characteristics of activated brain areas. The results showed: With RSI increasing, the activation range of P300 increased, especially in the frontal position. When RSI = 1000ms, the implicit learning group's active regions were most widely distributed, and related brain regions mainly involve occipital, parietal and frontal brain areas. The relevant EEG studies of explicit cognitive processing had drawn the same conclusion. For example, Nessler et al (2005) found that the performance of implicit perceptual priming was a central parietal ERP effect during 300ms and 450ms; while the explicit memory performed in two time periods: frontal ERP effect in 300-450ms and the ERP effect distributed in the back of the scalp in 500-650ms. Boehm et al (2005) found that implicit memory appeared in the central roof area in 350-650ms, and explicit memory was the maximum value of frontal area in 275-325ms and top area in 375-425ms. Guo Chunyan et al (2006) found that: explicit memory mainly performed in the prefrontal area and frontal area, while implicit memory mainly performed in the central and parietal areas. Thus it seemed that we could draw the conclusion that the brain orientation's differences in different consciousness processing as following: high degree of awareness activated wide range and dispersion; low degree of awareness relatively small and concentrated. In summary, there was a trend that the awareness showed from low to high, and the activated brain areas change from the back to the front continuously.

Problem and Prospect

On the studies of children's cognitive strategy of mathematics, psychologists care much about the following problems: Firstly, two kinds of mental status are involved in the strategy discovery: in conscious or unconscious. However, which status on earth is the former process still in controversial. Some argue that children discover strategy in conscious firstly. While more and more scholars today think that strategy finding consciously is based on an unconscious way. How to process the way from unconsciousness to consciousness and whether the outside explicit strategy of guidance will affect the child's implicit strategy? To answer these questions, we need further discussion. Secondly, according to new strategy learning, which way is better: guidance by teaching or implicit strategy use by student themselves? The former studies proved the effect of teaching strategy. However there are questions in using the strategies. The further researches should centre on the difference of the effects of the two methods so that we can provide better conditions to help children master strategies. Thirdly, the content of the study need to be extended. For example, investigating the individual difference of strategies utilizations. Whether some inherently do better with the implicit strategies while others are more adapted to the outside guidance.

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